THINGS of science

GRAVITY

Created and distributed without profit by Science Service, Inc., 1719 N Street, N.W., Washington, D. C. 20036. E. G. Sherburne, Jr., Director. Ruby Yoshioka, Editor.

GRAVITY

Gravity controls the solar system. It holds it together, keeping the planets and the moons in their proper paths. Gravity keeps us from flying off into space, causes rivers to flow downhill and creates high and low tides along our beaches. It guides a thrown ball along a parabolic curve and makes autumn leaves fall to the ground. It governs our lives. Every time we move or walk, we automatically take gravitation into consideration. A baby who is just learning to stand up is really learning to cope with gravity.

What is gravity? This mysterious force has been wondered about and investigated since time immemorial and is still being studied. Among the many who have delved into the whys of gravity, three great scientists stand out as having contributed most to its understanding: Galileo Galilei, Isaac Newton and Albert Einstein. But no one has yet been able to tell us what gravity exactly is nor what produces its force. We know only that it exists and what it does.

With the materials in this unit you will observe the interesting way objects behave under the influence of gravity and also learn something about how its force can be applied.

First examine your specimens.

MARBLES—Two.
THUMBTACKS—Two.
LEAD SINKER
WOODEN BEAD
WOODEN DOWEL
PAPER CUP
RUBBER BAND
STRING—Fifty-four inches long.
WIRE—Twelve inches long.
COLORED PAPER—3 x 3 inches.
COLORED PAPER—3 x 5 inches.

Cut your string into the following lengths: 6 inches, 7 inches and 41 inches.

GRAVITY MAKES THINGS MOVE

You are all familiar with the story of Newton and the apple tree. When he saw an apple fall, the legend goes, he started wondering about gravity and why an object should fall down instead of up. After years of study and calculations, he came to the conclusion that all objects in the universe attract each other, from the tiniest particle to the largest of heavenly bodies, and formulated his Law of Universal Gravitation.

Newton stated in his Law that there exists between each pair of particles in the universe a gravitational attractive force which is directly proportional to the prod-

uct of their masses and inversely proportional to the square of the distance between them. Thus, the greater the masses of objects, the greater their attractive forces for each other, and the further apart they move, the weaker the force becomes.

This law accounts for the behavior of all objects under the influence of gravity, why they fall as they do and why planets orbit about the sun, and also implies that gravitational attractive forces between objects can extend for millions of miles across space.

Newton also showed that a spherical body attracts as if all of its mass were concentrated at its center. That is why everything that drops to the earth's surface is pulled straight toward its center.

The force of gravity is a weak force and is insignificant between ordinary objects, such as a chair and table, or books on a shelf. They will not move toward each other, no matter how long they stay in the same position. However, for massive bodies like the earth and other planets, and the sun, it acquires great importance because the attractive force of gravity increases directly with mass. The sun's gravitational pull keeps the planets in their orbits, and the earth's attraction prevents us from falling off the earth and the

moon from escaping into space.

The force of gravity passes through everything. Nothing obstructs it, whether gas, liquid or solid.

Experiment 1. Drop one of your marbles on a table, then over a pan of water and next through the air. The marble is pulled toward the ground regardless of the type of matter beneath it. Things will drop to the floor at the top of a tall building as well as in a basement, at the top of a mountain or in the valley below.

As you know, anything that is thrown into the air comes faithfully back to earth. If you should jump into the air, you would be quickly snapped back.

Experiment 2. Place your empty THINGS box on the table. Does it move? Give it a push. You have exerted a force on the box causing it to move. When an object is at rest and a force is applied that puts it into motion, the object undergoes a change in velocity, or is accelerated.

When you see a branch of a tree swaying back and forth, you know that it is not moving under its own power, but that something is making it move—an invisible force, the wind.

Gravitational force like the wind is invisible. If you should push your box off

the table, it would drop to the floor. If no force were exerted on it to pull it downward, it would remain in the air. But since the earth's gravity is constantly pulling everything toward its center, anything that is not supported from beneath falls to the ground, or undergoes acceleration.

As you can see, for anything to move, up, down or sideways, a force must be applied to it.

Experiment 3. Hold the box in your hand. Gravity is pulling it down, but your hand is exerting an upward force at least equal to the pull of gravity on the box, so it remains stationary.

Hold a narrow sheet of letter paper outstretched horizontally and place the box on it. Does it remain there or drop to the floor? If it falls, the sheet of paper cannot balance the pull of gravity on the box. The box moves in the direction of the greater force.

Experiment 4. Now place the box in the palm of your hand again. Move your hand upward. The box moves upward too. The force exerted by your hand is greater than the gravitational force so the box moves along with your hand. What would happen if you put a very heavy object in the box?

Experiment 5. Place the wooden bead and lead sinker in your hands and note the differences in their weights. Hold them at exactly the same level (about three feet above the floor) and then let them go at the same time. Do they reach the floor at the same instant? Repeat the experiment with other unbreakable objects of different weights.

Galileo is said to have been the first person who demonstrated the fact that all objects, light or heavy, big or small, fall to the ground with the same velocity.

Experiment 6. Hold the 3 x 3-inch colored piece of paper horizontally at the same level as the lead sinker and then release the two at the same time. What happens? Does the paper float down lazily while the sinker speeds to the floor?

Now roll the paper up into a tight ball and drop it again with the sinker. What are your results? Since the weight of the paper has not changed and you have shown that light and heavy objects fall at the same speed from the same height, there must be some other reason why the paper traveled more slowly to the floor when it was a square sheet than when it was rolled into a ball. The reason is air

resistance. A flat sheet of paper has a greater surface area exposed to the air and encounters more resistance than a small round object. If there were no air resistance as in a vacuum, both the square of paper and the sinker would fall at exactly the same speed.

When an object drops toward the surface of the earth, during the first full second of its free fall (disregarding air resistance) its speed increases steadily from zero to 32 feet per second. During each following second of fall, it is accelerated another 32 feet per second. This means that a freely falling body starting from rest would attain a speed of 32 feet per second the first second, 64 feet per second after two seconds, 96 feet per second after three seconds and so on. The acceleration of gravity therefore is 32 feet per second per second and is usually written 32 ft./sec^2. During the first second of free fall an object falls 16 ft.

Experiment 7. Raise one end of a long table with a smooth surface about two inches. Roll the dowel down the table. Does it roll faster at the beginning or the end of the slope? Note that it gradually gains speed as it rolls along.

While the inclined plane supports the dowel in its downward path, the motion

of the dowel is similar to that of free fall, except that its velocity is slowed by the slope.

Experiment 8. Take a piece of cardboard about a foot long and allow the dowel to roll down its surface while it is held at various angles. You will observe that the steeper the slope, the faster the dowel travels. Now you can see why a person can ski or sled much faster down a steep slope than a gentle one.

Experiment 9. Raise the end of the table about one inch and keep it inclined by placing books or other convenient objects under the legs. Allow the dowel to roll down the surface and check to see that it travels along a straight path. Place a long strip of paper along the length of the table. On this strip you will mark the distances traveled by the dowel after 1, 2 and 3 or more seconds. To clock the time, use a watch with a second hand or even better, use a metronome set for one-second intervals.

Allow the dowel to roll down alongside the strip of paper and mark the distances it travels during each second. If the dowel travels too fast, lower the legs of the table slightly. Measure the distances. Do you find that the dowel covers in two seconds approximately four times the distance it

did in the first second and nine times the distance in three seconds? Sixteen times the distance in four seconds?

This experiment is somewhat difficult and you may need to do it several times before you can get good results.

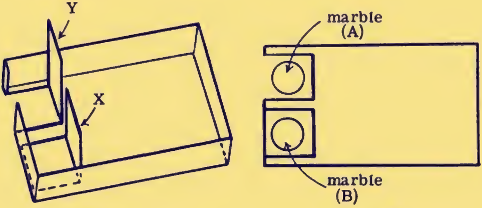
Repeat the experiment with larger and heavier cylindrical objects, such as a fruit juice can or a plastic rod. The speed of travel and the distances covered should be the same on the same inclined plane.

The distance a falling body travels increases as the square of the time. Therefore, if the dowel traveled three inches the first second, it would travel 12 inches in two seconds ($2^2 \times 3$ inches) and 27 inches in three seconds ($3^2 \times 3$ inches).

Some of the gravitational energy is used up in getting the dowel to roll down the hill, but this can be disregarded here because the experiments are not that precise.

Experiment 10. Make an opening one inch long on each side, in the cover of your THINGS box, flush with the narrow edge and about 3/8-inch to one side of the center. Cut along three sides only—the side against the narrow edge of the box and the two sides parallel to the length of the box. Lift up the cut strip thus produced and fold it back so that it stands at a right angle to the opening (Fig. 1a, X).

Next to this opening about the same distance on the other side of the center, make another opening of the same size, but this time cut through the edge of the box also. Fold the strip back as before, at a right angle to the one-by-one-inch square hole (Fig. 1a, Y).



a. b.

Fig. 1

Do this experiment in an uncarpeted room. Place the box about half an inch from the edge of a table with the openings toward the edge. Place a marble in each hole (Fig. 1b).

Give the box a sharp push being sure that the openings clear the edge of the table, but do not let the box go. One marble (A) will travel away from the table and fall to the floor in an arc, while the other (B) will fall straight down. Listen carefully for the sound of the marbles striking the floor. Do they reach the

floor at the same time? (You may need to practice this a few times to get the desired result.)

When two objects are released at the same time from the same height, one along a horizontal path and the other straight down, they will both take exactly the same length of time to reach the ground, regardless of the distance traveled by the object impelled horizontally.

Experiment 11. Roll one of your marbles across the flat surface of a table. The marble's inertia, or its tendency to travel along at the same velocity in the same direction, keeps it moving across the table.

Experiment 12. Now shoot the marble across the surface and off the edge of the table. Note the curved path it takes as it falls to the ground. It traces a parabolic curve.

In Experiment 11, the marble supported by the table traveled in one direction only. However, here, as the marble with no support from beneath is going in one direction at a steady rate, it is also being pulled toward the earth by gravity with increasing speed. The two motions are independent of each other and the marble takes a parabolic path (Fig. 2). All freely

falling bodies projected horizontally move along a similar curve which is also referred to as a projectile path.

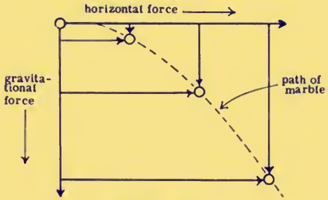


Fig. 2

A thrown ball, an arrow shot into the air or the water shooting out from a garden hose, all trace parabolic curves.

Allow your wooden bead to bounce freely on a table and note the path it describes. Pour water from a pitcher or a teakettle and again you have a parabolic curve. When you jump from a high place you also follow a parabolic path.

Experiment 13. There is another way to demonstrate the parabolic path taken by a falling body. Fold a piece of cardboard about six or more inches long. Lift the end of a long table several inches to make an inclined plane. Then allow the marble to roll down the groove in the cardboard which is held so that the marble rolls straight across the inclined plane for a short distance before travelling down

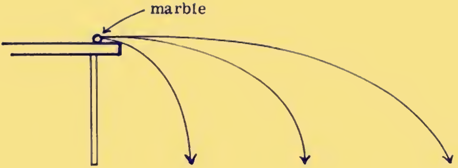


Fig. 3

the plane.

Experiment 14. Make the table level again. Shoot a marble off the edge of the table several times, applying a greater force each time. Note that as the speed with which it is launched is increased, it travels further horizontally and describes a larger curve as it makes its way to the ground (Fig. 3).

Newton, observing the paths taken by objects projected horizontally, theorized that if a cannon ball could be fired parallel with the horizon with enough force from the top of a high mountain it could achieve a path that would match the curvature of the earth and travel completely around it. As it moved along at high speed the cannon ball, pulled by gravity, would fall constantly toward the earth tracing a curved path. But since the

earth's surface is curved, it would never reach the ground and continue around the earth in an orbit if there were no air resistance.

Thus, Newton was the first to describe how an artificial satellite could be launched and remain aloft in an orbit around the earth.

Since no mountain is high enough to launch a satellite, it must be lifted to the desired height by means of a rocket and placed into orbit in several stages by firing additional rockets, first to put it in a horizontal path and then to give it enough speed to stay in orbit.

WEIGHT AND MASS

The pull of gravity on any object is referred to as its weight. If there were no gravity, there would be no weight.

You can measure the force of gravity by a simple scale that depends directly on gravitational pull with the rubber band in your unit. Spring scales in grocery stores and bathroom scales are of this type.

Units of weights have been standardized for convenience, but any constant unit can be used for a scale as long as it is consistent and workable. For our purposes, let us use the sinker as a unit of weight.

To make your scale, first make two holes opposite each other in your paper cup about 5/8 of an inch from the rim. Thread the six-inch piece of string through the holes to make a handle knotting the string to hold it in place.

Cut your rubber band at one end to make a single long strip. Then tie it securely to the center of the cup handle.

Paste the 3 x 5-inch paper in your unit over the bottom of your THINGS box. Draw a line down the center of the paper lengthwise. Insert one of your thumbtacks through the rubber band about 3/4 of an inch from the free end. While holding the box upright, stick the thumbtack into the center line near the top allowing

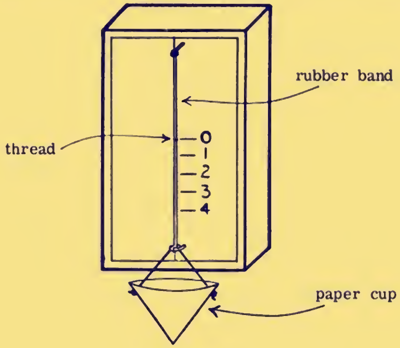


Fig. 4

the cup to hang freely with its rim just below the edge of the box (Fig. 4).

Tie a white (or any color that will show up) thread at the center of the length of rubber band to mark the zero point of your scale. Hang the scale upright in any convenient spot being sure the cup is not obstructed in any way. Draw a line about 1/4-inch long just beneath the thread and place a 0 alongside it. Place your sinker in the cup and make a line just beneath the new position of the thread and mark a 1 next to it. Measure the distance from 0 to 1 carefully and mark off divisions below the 1 to show the weights of 2, 3 and 4 sinkers.

Remove the sinker from the cup and check to see if the thread returns exactly to the zero point. If not, correct your scale.

Experiment 15. Place a marble in the cup. Does it weigh more or less than one sinker? How many marbles would weigh two sinkers? Weigh other small objects.

NOTE: The scale you have calibrated is true only for this instrument. If you should make another scale using a spring or a different rubber band with a different tension, you would have to recalibrate the scale for these particular materials.

If you took your scale to a high moun-

tain, would the sinker still weigh the same? Remember the inverse-square law which states that the force of gravity varies inversely with the square of the distance. This means that an object loses weight as it moves away from the earth. If it weighed 4 pounds at the earth's surface, at an altitude twice the distance from the earth's center (or about 4,000 miles up) it would weigh $\frac{1}{2}^2$ or ¼ as much, or only one pound.

At three times the distance the attractive force of gravity is $1/3^2$ or $1/9$ as much and so on.

The earth bulges at the Equator and the surface of the earth is further away from the center than at either pole. What effect would this have on the weight of the sinker if it were moved from the Equator to the North Pole?

Gravitational pull varies also with the nature of the material in the earth's crust. It is greater in locations where there is a large amount of dense rock near the surface than in areas made up mostly of sandy or loamy soil. An instrument known as a gravity meter is used by geologists to check the nature of the soil in different locations by means of gravitational force.

While all these changes are taking place on the weight of an object, what is hap-

pening to its mass? Does it change too? When we take a sinker from the North Pole to the Equator, or from the earth's surface to the moon, it is still the same sinker with the same properties. Its mass does not change.

The weight changes since it is the measure of the pull of gravity on a mass. But mass which is a characteristic of the object does not change. It is important to understand the difference between weight and mass. The two are often confused.

ENERGY OF A FALLING BODY

Experiment 16. Stand the top of your THINGS box on its side, or if you wish, substitute a square of cardboard.

Tie one end of the 41-inch length of string to the sinker, very securely so it won't come loose.

Hold the string about one foot from the sinker and then let the sinker hang so that it is about a half an inch away from the center of the box. Raise the sinker to one side and release it. What happens when it strikes the box? The force of its fall causes the box to move.

Objects in motion, such as falling bodies, have the ability to do work on whatever they strike. Thus gravity can be

made to work.

The word work in mechanics refers to the effect that is accomplished when a force is exerted on a body and moves it a certain distance. If there is no motion no work has been done. When you lifted the sinker you did work. The amount of work you did is equal to the product of the weight of the sinker and the distance it was raised.

The sinker in your hand, held at a certain level, is doing no work, but it possesses the ability to do work, as you have seen, when it falls and strikes another body. This ability is called potential energy. The sinker resting in your hand has energy stored that is equal to the energy required to lift it to its position. It retains this energy as long as it is held in the same position. If you lift the sinker higher, its potential energy is increased, since potential energy is equal to the weight of an object times the height.

The stored energy due to elevation is called gravitational potential energy.

Experiment 17. Lengthen the string to two feet and then allow the sinker to swing from a height of two feet and strike the box. Does it cause a greater movement in the box? Since its potential energy was increased its ability to do work was also

increased.

If a heavier object were tied to the string would the force of impact be greater? Why?

A heavy weight on the end of a chain swung back and forth like a pendulum is used by wreckers to demolish buildings. They are making use of gravitational potential energy to do work.

Water directed to flow into a water wheel or turbine to drive other machinery is another example of the use of gravitational potential energy.

The potential energy of a body is its stored energy. As soon as the body begins to move the potential energy becomes kinetic energy, or the energy of a moving body.

THE PENDULUM

Experiment 18. Hold the string attached to the sinker and allow the sinker to hang freely. It hangs straight down. This is of course because gravity pulls all things toward the center of the earth. The sinker and string may be used as a plumb line like that used by builders to be sure walls and doors are perfectly vertical.

Still holding the string in the same position, with your other hand lift the sinker to one side with the string taut and then let it go. The weight swings back and

forth continuously until it finally comes to a stop, always at the same place. A weight that swings back and forth is called a pendulum.

Experiment 19. Hold the string 20 inches from the sinker or loop it over a convenient nail where the pendulum can swing freely. Don't cut the string. With the string taut, lift the sinker to the side and then let it go. Count the number of full swings per minute. When the pendulum swings from one side to the other and returns to its starting point it makes one full swing (Fig. 5).

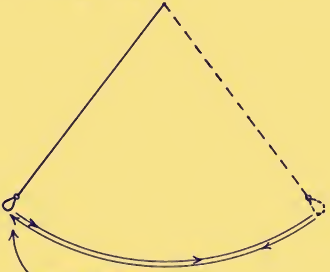


Fig. 5

The number of full swings per second is referred to as the frequency of the pendulum and the time required to make a full swing is called the period.

Does the frequency of the pendulum

change as the swings become shorter? Note that the frequency does not change. This is true, however, only if the arcs are shallow and the amplitude of the swings is not very great.

Experiment 20. As the pendulum is swinging, gradually shorten the string. What happens? Count the swings. Does the pendulum swing faster or slower as the string is shortened?

Lengthen the string to 39 inches. What is its frequency? Does it make one full swing about once each two seconds or 30 times per minute? Shorten the string to 9¾ inches. What is its frequency now? When the string is one-fourth as long, the pendulum swings twice as fast.

Galileo showed that the change in frequency is related to the acceleration of gravity. Refer to Experiment 9 with the dowel in which you showed that an object rolling down a plane will go four times as far in twice the time.

By making the pendulum string four times as long, its arc is also increased by four times. When the arc is shallow the acceleration is similar to that on a straight track. The period of the pendulum should therefore be doubled.

Experiment 21. Attach a heavier weight to the string and then allow it

to swing with the string 39 inches long. Does the frequency increase, decrease or remain the same? You will find that the pendulum will still swing once each two seconds. The weight of the bob has no influence on the frequency or period.

Can you explain why? If you refer to your experiments with freely falling bodies you will have your answer.

The frequency and period of a pendulum depend only on its length.

The pendulum in a grandfather clock is made so that it ticks off one second with each half swing.

Experiment 22. Allow your 39-inch pendulum to move in a circle or an ellipse. Time each complete revolution. What do you find? Each full rotation the pendulum travels is equal to one full swing of the same pendulum.

CENTRIFUGAL FORCE

Experiment 23. Hold the string about 12 inches from the sinker and swing it around at a moderate speed with your arm outstretched to prevent the sinker from striking you. Be sure the string is tightly knotted. Note the pull on the string as the sinker rotates. Since a moving object always tries to travel in the same direction it is going, the sinker is pulling away from the curved path trying to move

along a straight line. This produces an outward pull on the string. This outward force is called the centrifugal force or centrifugal effect.

Experiment 24. Swing the sinker around faster. Does the outward pull become greater?

Experiment 25. Rotate the sinker at a moderate speed close to the surface of a smooth floor or the top of a table. Hold the string as close to the surface as possible so the string is parallel to the surface but not touching it. Then let it go. In which direction does the sinker speed off? It goes off at a tangent to the circle (Fig. 6).

As long as the string is held while you are rotating the sinker and a pull toward the center is applied, the sinker remains in its circular path. This force directed toward the center is called the centripetal force.

The sinker exerts an outward force on

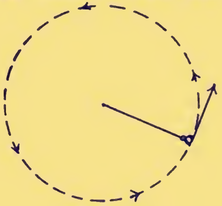


Fig. 6

the string as it is whirled around which we feel in our hand, while the string pulls the sinker inward. Thus, the centrifugal force acts on the string and the centripetal force on the sinker.

Experiment 26. Swing the sinker around again and then slow it down. Does it drop? If so, the centrifugal force is not great enough to hold the sinker in its circular path. If the centrifugal force and centripetal force are equal in magnitude, the sinker will remain in the air.

Experiment 27. Whirl the sinker around again. As you do so, pull slowly on the string with your other hand. Does the speed of rotation increase or decrease? The shorter the string, the faster it rotates.

Experiment 28. Tie your wooden bead to the other end of the string. Whirl it around. Compare the minimum rotational speed needed to keep the wooden bead in the air with the speed required to keep the lead sinker in the air with the same length of string. Lighter objects require less circular velocity to maintain their rotational paths.

Centrifugal and centripetal forces are applied in various household and industrial devices. In the spin dryer in a washing machine, water is removed by rotating

the clothes and allowing the water to fly off at a tangent. Centrifuges are used to separate lighter liquids from heavier ones and liquids from solids by regulating the speed of of rotation.

Experiment 29. Take the paper cup you used in making your scale and remove the rubber band. Tie a length of string to the handle of the cup. Then place a marble in the cup. If you turn the cup upside down, the marble quickly falls out.

Whirl the cup with the marble in it and note that the marble remains in the cup as long as it is being rotated, even if the cup is upside down. The centrifugal force which tries to keep the marble traveling in a straight line pushes the marble against the bottom of the cup while the centripetal force pulls the cup toward the center. The marble is kept suspended by the two opposite forces.

WEIGHTLESSNESS

When a spacecraft is placed in orbit around the earth or around the moon, in order to stay in orbit, the gravitational pull on the spacecraft must be exactly countered by the force of its motion. If not, it will either fly off at a tangent or crash to the ground.

The pull of gravity acting on the spacecraft is like the string pulling on the sinker and it exerts a centripetal force on it just balancing its tendency to travel along a straight path, or the centrifugal effect.

At an altitude where the gravitational force is equal to the centrifugal effect, objects have no weight. Therefore, all objects including the astronauts if unhindered will float about freely.

Experiment 30. Make a small loop at one end of your wire. Then insert the wooden bead in the wire from the other end. About 2 inches from this end, bend the wire at a right angle. About 2½ inches from this angle bend the wire in the opposite direction at a right angle also, rounding the bend (Fig. 7) so the bead can move readily up and down the wire.

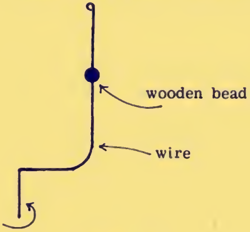


Fig. 7

Hold the wire upright and whirl it. The

bead will shoot up to the end of the wire by centrifugal force. When you stop rotating the wire, the bead will drop down because the force keeping it rotating has been removed.

Now whirl the wire, adjusting the speed of rotation so that the bead will remain at some position along the length of the wire, neither at the top nor the bottom. At such a point, the force of gravity and the rotational force are equal and the bead is weightless. You may need to practice a few times to get the bead to stay afloat.

Note that in order to stay aloft, the bead must be kept rotating. This is true of spacecraft and satellites too. They must keep moving about the earth in order to remain in orbit.

Objects in free fall are also weightless. In early experiments with weightlessness, airplanes were placed into a dive from high altitudes to allow astronauts to experience the effects of weightlessness.

PLANETARY ORBITS

The solar system, as mentioned, is held together by gravitational force. The gravitational pull between each of the planets and the sun is exactly balanced keeping them in their orbits.

The planets, however, do not travel around the sun in a perfect circle. They travel along an elliptical path.

You can draw ellipses of various shapes, narrow, medium or wide, to visualize the shape of the orbits.

Experiment 31. On a piece of cardboard, place the two thumb tacks about two inches apart. Tie the ends of the 7-inch piece of string together and loop it around the two thumbtacks. Place a pencil in the loop and trace an ellipse completely around the two tacks by holding the pencil against the taut string (Fig. 8).

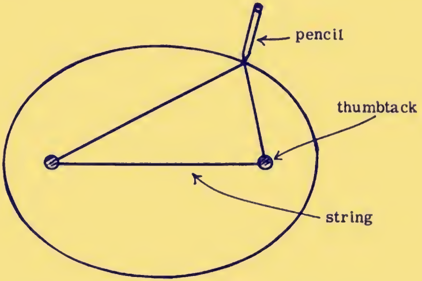


Fig. 8

Change the distance between the two thumbtacks and you obtain narrower or wider ellipses.

Johannes Kepler, a German astronomer,

discovered that the paths of planets around the sun are governed by two laws.

First, that each planet follows an elliptical path with the sun at one focus of the ellipse. In your ellipses, the position of the two thumbtacks are the two foci.

Second, that an imaginary line connecting the sun with the planet covers equal areas of space in an equal length of time. By mathematical deductions, he showed that a planet travels faster when it is close to the sun, or at perihelion, than when it is farther away from the sun, or at aphelion.

Newton related the elliptical path of planets to the inverse square law of gravitational force.

The planets, as they make their way through space, are affected by the gravitational force of other bodies that they may come close to. If the attractions are strong enough, their paths may be slightly swerved. The moon's gravitational force, although it cannot change the course of the earth's rotation, is strong enough to attract the water on the earth's surface

and create tides.

Einstein with his Theory of Relativity has approached the subject of gravity from an entirely different point of view, upsetting some of Newton's theories of gravitational interaction.

But the exact nature of gravity is still not solved and studies are still going on.

If you wish to pursue the subject further and delve into Einstein's theory and what it means, the references below will be helpful.

The Attractive Universe: Gravity and the Shape of Space, E. G. Valens, The World Publishing Company, New York.

Gravity, George Gamow, Doubleday, Garden City, N. Y.

The Riddle of Gravitation, Peter G. Bergmann, Scribners, New York.

Appreciation is expressed to Mr. Douglas Tate, National Bureau of Standards, for reviewing this booklet and for his helpful suggestions.

* * * * *